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UNITED STATES ATOMIC ENERGY COMMISSION / PLOWSHARE PROGRAM

project SEDAN

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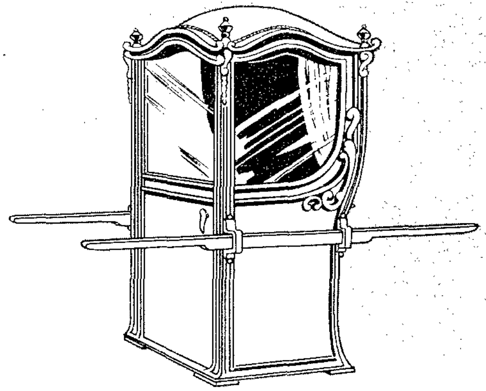

Close-in Air Blast from a Nuclear Event in NTS Desert Alluvium

L. J. Vortman

SANDIA CORPORATION

ISSUED: OCTOBER 2, 1964

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NUCLEAR EXPLOSIONS – PEACEFUL APPLICATIONS

PROJECT SEDAN

PNE-211F

CLOSE-IN AIR BLAST FROM A NUCLEAR EVENT IN NTS DESERT ALLUVIUM

L. J. VORTMAN

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Albuquerque, New Mexico

ABSTRACT

Close-in air blast from the Sedan event was considerably greater than expected on the basis of previous measurements of blast from nuclear events in basalt and from HE events in both basalt and alluvium. In spite of overranging of the pressure gages, the measurements permit derivation of a lower limit of peak overpressure and an upper limit on the amount of blast suppression resulting from charge burial. Comparison of Sedan blast suppression with that of previous buried HE and nuclear shots shows that Sedan blast suppression was considerably less than would have been predicted from HE shots at comparable burst depths. Sedan peak overpressures were two to three times those of Stagecoach III at approximately the same cube-root sealed burial depth and four times those of Scooter or Buckboard 12 (at or near the burial depth for maximum crater). The scaled total positive-phase impulse for Sedan was about the same as those of Stagecoach III, Buckboard 12, and Scooter, while the scaled positive-phase duration was much shorter. Blast suppression factors, based on peak overpressure and impulse, reflect the above differences. The differences may be due, in part at least, to a higher pressure in a relatively smaller cavity volume at the time of venting for Sedan than for the HE shots.

ACKNOWLEDGMENTS

The author wishes to thank Mr. Ralph E. Reisler, Ballistic Research Laboratories, for making the blast measurements and reducing the data for Project Sedan, and Mr. F. Shoemaker for coordinating the project in the field.

TABLE OF CONTENTS

CLOSE-IN AIR BLAST FROM A NUCLEAR EVENT IN NTS DESERT ALLUVIUM

CHAPTER 1

INTRODUCTION

1.1 Objective

The air-blast measurement program had as its objective the determination of the overpressure time-distance relationship at ground level along a single blast line. The purpose of the measurements was to determine the extent of close-in blast suppression and to compare this suppression with those of other subsurface detonations. The experiment extends blast observations from a 1/2 kiloton high-explosive (HE) charge (Project Scooter)[1] to a nuclear charge in alluvium with a yield of 100 kilotons. That is, Sedan was 200 times larger than any previous detonation at a comparable burial depth. Data from this experiment yield some knowledge on the differences in blast suppression between Sedan and the smaller shots but they do not indicate conclusively to what extent these differences should be attributed to differences in the type of explosive (nuclear or chemical), differences in the media, or differences in the yield.

1.2 Background

Table 1.1 summarizes cratering experiments[1-8] using charges larger than 256 pounds, both HE and nuclear, on which close-in air-blast measurements have been made; it includes charge weight, burst depth, and the source of information on these experiments. Table 1.2 summarizes experiments with 256-pound charges. The conclusions from these earlier experiments were that:

a. Differences in peak overpressures of the close-in air blast emanating from HE charges buried in different media are small if they exist at all[6]. This conclusion was based on a comparison of blast from

Stagecoach and Buckboard charges of equal yield in alluvium and basalt, respectively. The peak wave in both cases was that attributable to the venting gases. The initial ground-shock-induced peak was considerably less than the main peak and was slightly lower in alluvium than in basalt. Some media differences, however, were noted for 256-pound charges at the deeper burst depths.[9]

b. There were no detectible departures from cube-root scaling of blast phenomena.[5,6]

Table 1.1 makes it clear that, based on cube-root scaling of burst depth, the best comparisons for Sedan are the Stagecoach III HE shot and the Danny Boy nuclear event.* If $W^{1/3.4}$ scaling is used, the comparisons should be with Scooter and Danny Boy; Sedan falls nearly midway between Buckboard 12 and 13. On the basis of overburden scaling, the best comparison is with Stagecoach I, Buckboard 13, and Scooter. Based on overburden scaling and density considerations, the best comparisons are with Buckboard 13, Stagecoach I, and Danny Boy. There has yet been no experimental evidence of departures from cube-root scaling of air blast from subsurface bursts. Hence, only cube-root scaling will be considered in this paper.

In view of scaling uncertainties, greater emphasis is given here to the comparison with Scooter, since one may not wish to base the comparison on the same scaled burst depth but rather on the fact that charges were at or very near the optimum burial depth, as both Scooter and Sedan presumably were. This choice avoids the dilemma which arises from the fact that crater dimensions, including burial depth, scale as a power of yield or charge weight smaller than one-third, whereas no departures from cube-root scaling have been observed for air blast.

---

*Since the crater dimensions of subsurface bursts scale as a power of yield smaller than 1/3, one may wish to make a comparison for air blast on the basis of other than cube-root scaling.

TABLE 1.1

Shot	Date	Charge weight*	Medium	Scaled Burst Depths $\frac{DOB}{W^{1/3}}$	$\frac{DOB}{W^{1/3.4}}$	$\frac{DOB(DOB+k)^{1/3}}{W^{1/3}}$ †	$\frac{DOB\ \rho g(DOB+k)^{1/3}}{W^{1/3}}$ †	Reference No.
Jangle HE 1	8/25/51	2,560 lb	NTS alluvium	0.15	.204	.404	6.0	2
Jangle HE 2	9/3/51	40,000 lb	NTS alluvium	0.15	.227	.424	6.3	2
Jangle HE 4	9/9/51	2,500 lb	NTS alluvium	-0.15	-.204	----	---	2
Jangle HE 3	9/15/51	2,500 lb	NTS alluvium	0.5	.691	1.45	21.6	2
Jangle S	11/19/51	1.2 kt	NTS alluvium	-.026	-.046	----	---	3
Jangle U	11/29/51	1.2 kt	NTS alluvium	.13	.226	.423	6.28	3
Teapot ESS	3/23/55	1.2 kt	NTS alluvium	.50	.890	2.18	32.41	4
Stagecoach I	3/15/60	40,000 lb	NTS alluvium	2.3	3.50	10.71	159	5
Stagecoach II	3/19/60	40,000 lb	NTS alluvium	0.5	.76	1.63	24.17	5
Stagecoach III	3/25/60	40,000 lb	NTS alluvium	1.0	1.52	3.74	55.17	5
Buckboard 13	8/24/60	40,000 lb	Basalt	1.75	2.66	7.25	126	6
Buckboard 11	9/14/60	40,000 lb	Basalt	0.75	1.14	2.49	43.4	6
Buckboard 12	9/27/60	40,000 lb	Basalt	1.25	1.90	4.72	82	6
Scooter	10/13/60	1,000,000 lb	NTS alluvium	1.25	2.15	6.48	96.3	1
Danny Boy	3/5/62	0.42±.08 kt	Basalt	$1.165\pm^{.065}_{.065}$	$1.993\pm^{.094}_{.100}$	$5.77\pm^{.32}_{.32}$	$100\pm^{5.6}_{5.6}$	7
Sedan	7/10/62	100 kt±20 kt	NTS alluvium	1.085	2.30	8.82	130	8

*pounds (lb): indicates high explosive, kilotons (kt): indicates a nuclear detonation.

†k is the number of feet of the medium the lithostatic pressure of which equals atmospheric pressure.

TABLE 1.2

Shot	Date	Charge Weight	Medium	$DOB/W^{1/2}$	Reference
101	6/28/52	256	Utah dry clay	1	9
102A	7/6/52			1	
104	7/13/52			-.13	
105	7/17/52			1	
106	7/19/52			.26	
107	8/20/52			0	
202	9/14/52	256	NTS alluvium	1	
203	9/19/52			.5	
204	10/4/52			.26	
205	10/8/52			.13	
206	10/11/52			0	
207	10/15/52			-.13	
212	10/24/52			1.0	
301	9/15/53	256	California wet sand	0.5	
302	9/18/53			0.5	
304	9/23/53			0.75	
305	9/26/53			0.26	
306	10/8/53			0.13	
307	10/10/53			0	
308	10/13/53			-.13	
311	10/20/53	256	California Moist Clay	0.5	
313	10/24/53			-0.13	
401	10/23/53	256	NTS alluvium	0.5	
402	10/26/53			0.75	
403	10/28/53			0.13	
404	10/30/53			1.0	
405	11/2/53			0.26	
406	11/4/53			0.5	
Sandia I	1/20/59	256	NTS alluvium	1	10
	1/21/59			1	
	1/23/59			1.5	
	1/23/59			2	
	1/24/59			2.5	
	1/26/59			2.5	
	1/27/59			3.0	

A typical blast waveform resulting from buried chemical explosions is shown in Figure 1.1a. Project Danny Boy held surprises[11] in that the air-blast waveform was of the type shown in Figure 1.1b. For HE, the initial or ground-shock-induced peak was slightly higher in basalt (Buckboard 12) than in alluvium at the same cube-root-scaled depth (Scooter) (Figure 1.2). This is as one would expect from the differences in sonic velocity in the two media. However, the ground-shock-induced pulse was higher for Stagecoach III than for Buckboard 12 because of the shallower burial of the Stagecoach shot. The gas-venting pulse, however, was not greatly different between HE shots at equal scaled burial depths in the two media. The principal difference was that the shock gas-venting wave from the shot in alluvium decayed with distance more rapidly than that from the shot in basalt.

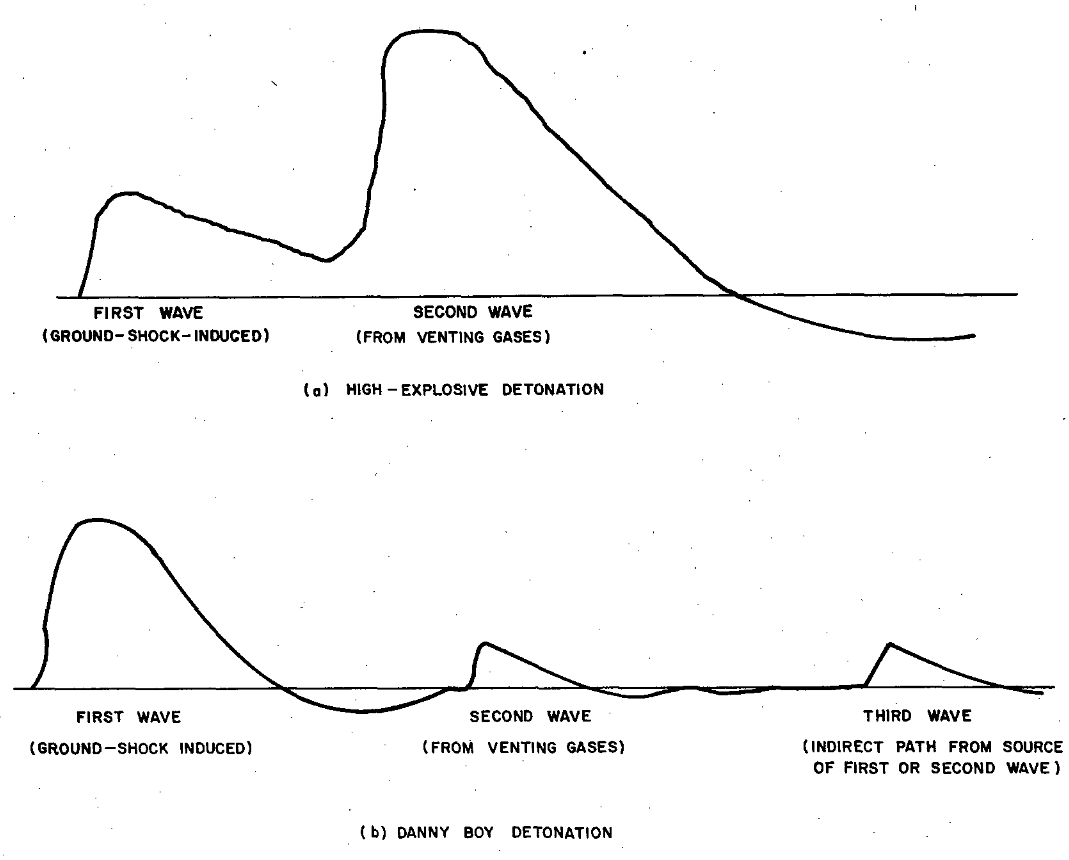


Figure 1.1

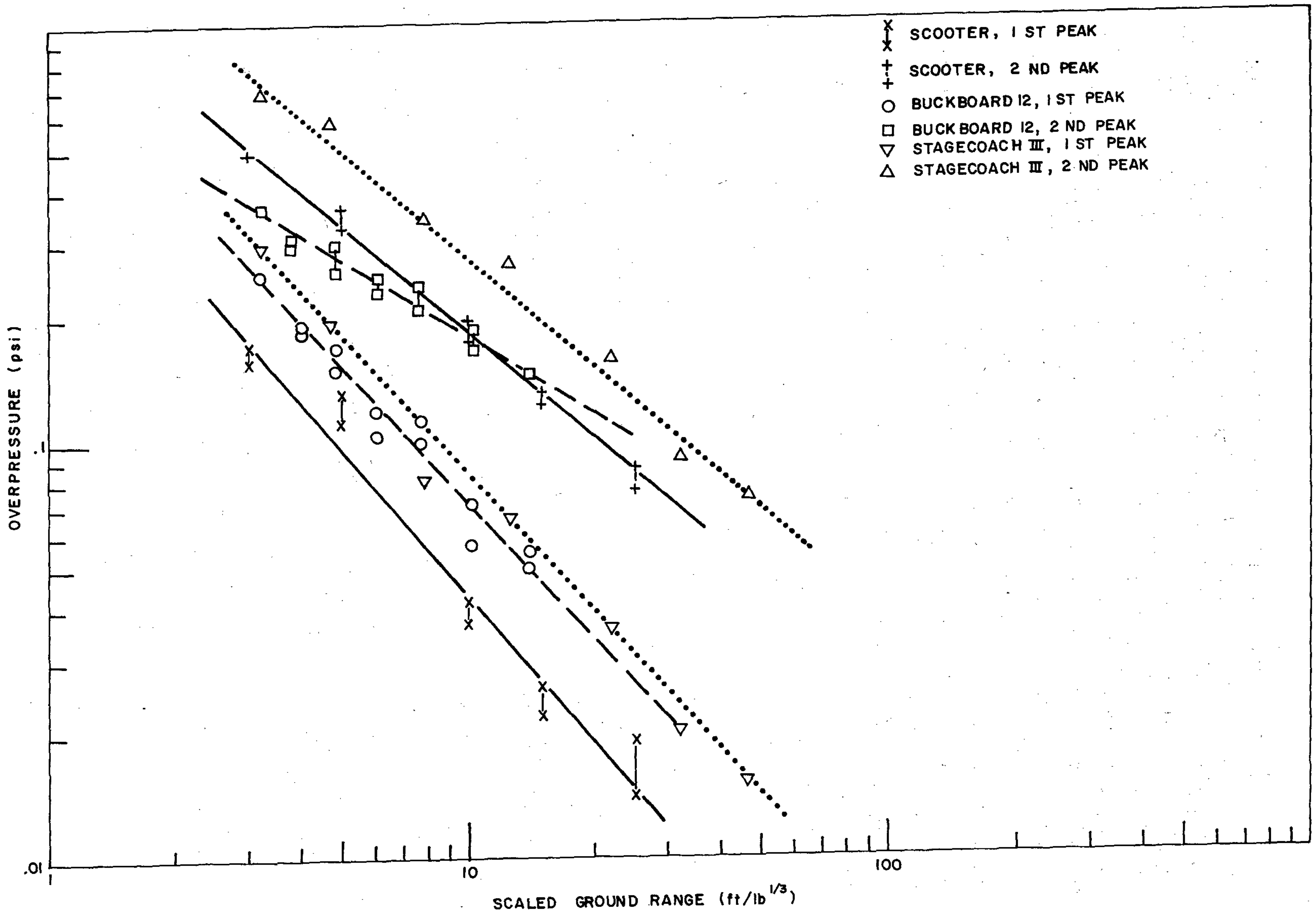

SCOOTER, 1 ST PEAK
SCOOTER, 2 ND PEAK
BUCKBOARD 12, 1 ST PEAK
BUCK BOARD 12, 2 ND PEAK
STAGECOACH III, 1 ST PEAK
STAGECOACH III, 2 ND PEAK
OVERPRESSURE (psi)
.1
.01
1
10
100
SCALED GROUND RANGE (ft/lb^1/3)

Figure 1.2

Figure 1.3 shows pressure-distance curves for the first and second peaks from Buckboard 12 and Scooter, together with the observed data from Project Danny Boy. The major surprise from Project Danny Boy was that the second peak was far smaller than the first peak, quite the opposite from the HE shot. This difference may be attributable to the lower gas pressure of a nuclear shot in a relatively dry medium. In view of the uncertainties in scaling burst depth, there was not sufficient difference between the first peaks observed in the Buckboard 12 basalt and Scooter alluvium shots and those of the Danny Boy shot, to say that there is an appreciable difference in the first peaks of HE and nuclear shots. It can be said, however, that the major difference between an HE and a nuclear shot in basalt is the almost complete absence of the gas-venting pulse (second peak) for the nuclear shot. This was the background within which ranges of expected peak overpressures were set for the Sedan event.

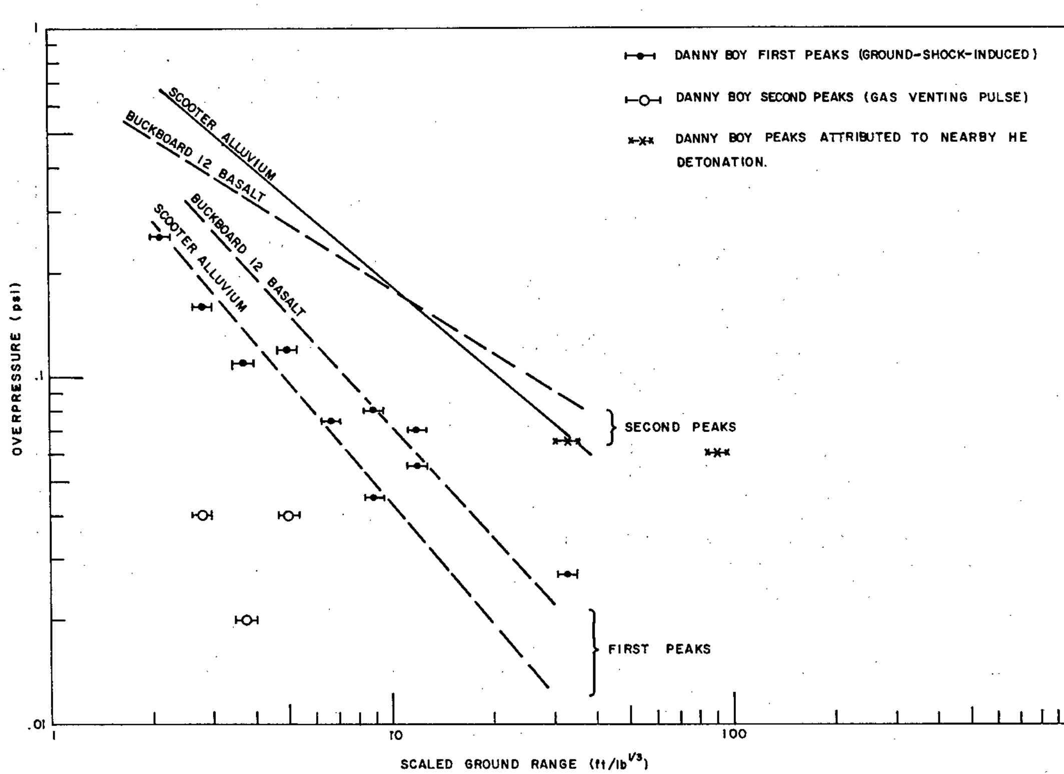


Figure 1.3

Figure 1.4 shows pressure-distance lines representing first and second peaks in the Scooter and Buckboard shots, together with the anticipated peak overpressure for the Sedan event. Expected overpressures for Sedan were originally based on the results of Scooter air-blast measurements. When the results of Danny Boy became available, the expected overpressure estimates were revised downward (as shown in the figure) to agree with the first peaks of both Scooter and Danny Boy. Since the lower second peak of Danny Boy was attributable to the low moisture content (~0.5 percent) of the medium, a larger second peak could be anticipated from Sedan, where the medium had a moisture content estimated at 5 percent. It was not expected, however, that this difference would raise the second peak to much more than the amplitude of the first (ground-shock-induced) peak.

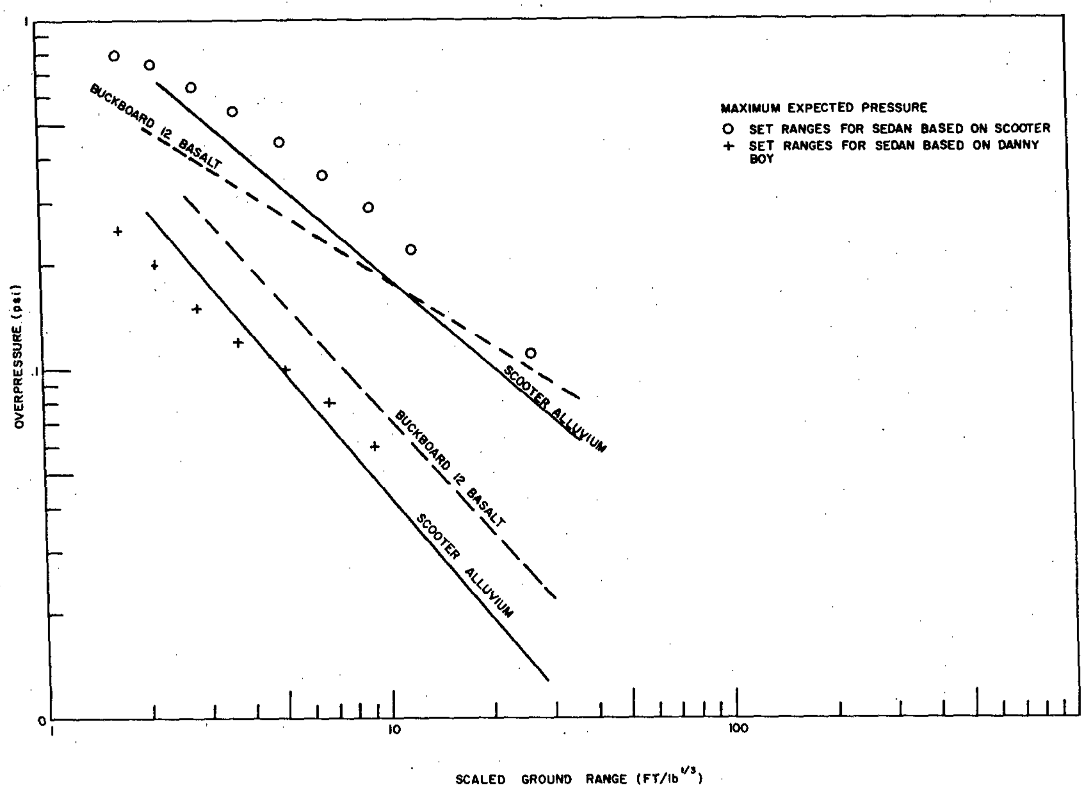


Figure 1.4

1.3 Instrumentation

Measurements were made with Ballistic Research Laboratory self-recording pressure gages. In these gages, a battery-operated motor drives a turntable carrying either an aluminized glass disc or a stainless-steel disc. A pressure-sensitive diaphragm, connected to a scribe, permits the pressure record to be inscribed on the disc as the turntable rotates. The gage motor is started by a timing signal at minus 1 second. Standard pressure-time gages (PT's) were used at Stations 1 through 6 and very low pressure gages (VLP's) at Stations 7 through 9.

Gages were located along the 150-degree radius at the following radial distances:

Station	1	2	3	4	5	6	7	8	9
Distance (ft)	1000	1260	1670	2200	2960	3970	5290	7050	15,500

CHAPTER 2

TEST RESULTS

2.1 Summary of Results

Table 2.1 summarizes the results of the pressure measurements. No records were recovered from Stations 1 through 4, and the gage at Station 6 was overranged and damaged. Peak pressures only were obtained at Station 8, because the gage turntable did not operate. Pressure records of those gages which did operate are shown in Figure 2.1. In the figure, time is shown from the arrival of the pressure signal; arrival-time data were not obtained because no zero-time fiducial was inscribed on the records. Venting occurred at 3.2 seconds, and the source of the air blast at the edge of the crater (611 feet) may be presumed at that time.

2.2 Peak Overpressure

At most of the stations the gages were overranged. At Station 5 the scribe struck the edge of the turntable, producing a flat section during the early portion of the wave. Peak overpressure was obtained by extrapolating back to shock arrival from that portion of the curve which occurred at a later time and was not distorted. There is a range of uncertainty in the extrapolation which has been indicated in both Table 2.1 and the subsequent evaluation of the data. Peak overpressure versus scaled distance, compared with Stagecoach III, Buckboard 12, and Scooter are shown in Figure 2.2.

No explanation is offered for the late spike which occurs on the records from Stations 5 and 7. Figure 2.1 makes clear that the waveforms were different from those of Figure 1.1, were indeed more like those from above-ground shots than from buried ones.

TABLE 2.1

Summary of Results

Station	Ground Range (ft)	Scaled Ground Range (ft/lb$^{1/3}$)	Type of Gage	Expected Pressure (psi) (†)	Expected Pressure (psi) (††)	Peak Pressure (psi)	Positive-Phase Duration (msec)	Positive-Phase Impulse (psi-msec)	Remarks
1	1,000	1.71	1/2 psi	0.80	0.25	Gage not recovered			Gage overranged
2	1,260	2.15	1/2 psi	0.75	0.2	Gage not recovered			Gage overranged
3	1,670	2.85	1/2 psi	0.65	0.15	Gage not recovered			
4	2,200	3.76	1/2 psi	0.55	0.12	Gage not recovered			
5**	2,960	5.06	1/2 psi	0.45	0.10	1.38*-1.70	998.6	771-818	Gage overranged
6***	3,970	6.79	1/2 psi	0.36	0.08	-----	-----		Gage overranged, no record
7	5,290	9.04	VLP	0.29	0.06	0.740*	1168.8	424	
8	7,050	12.05	VLP	0.22	0.06	0.717*			Gage did not run (peak value only)
9	15,500	26.50	VLP	0.11	0.06	0.035			

†Based on Scooter results.

††Based on Danny Boy results.

*Values obtained by extrapolation.

**Gage at Station 5 hit edge of turntable, producing a flat section during the early portion of the wave.

***Gage at Station 6 was blown about 175 feet by the blast wave.

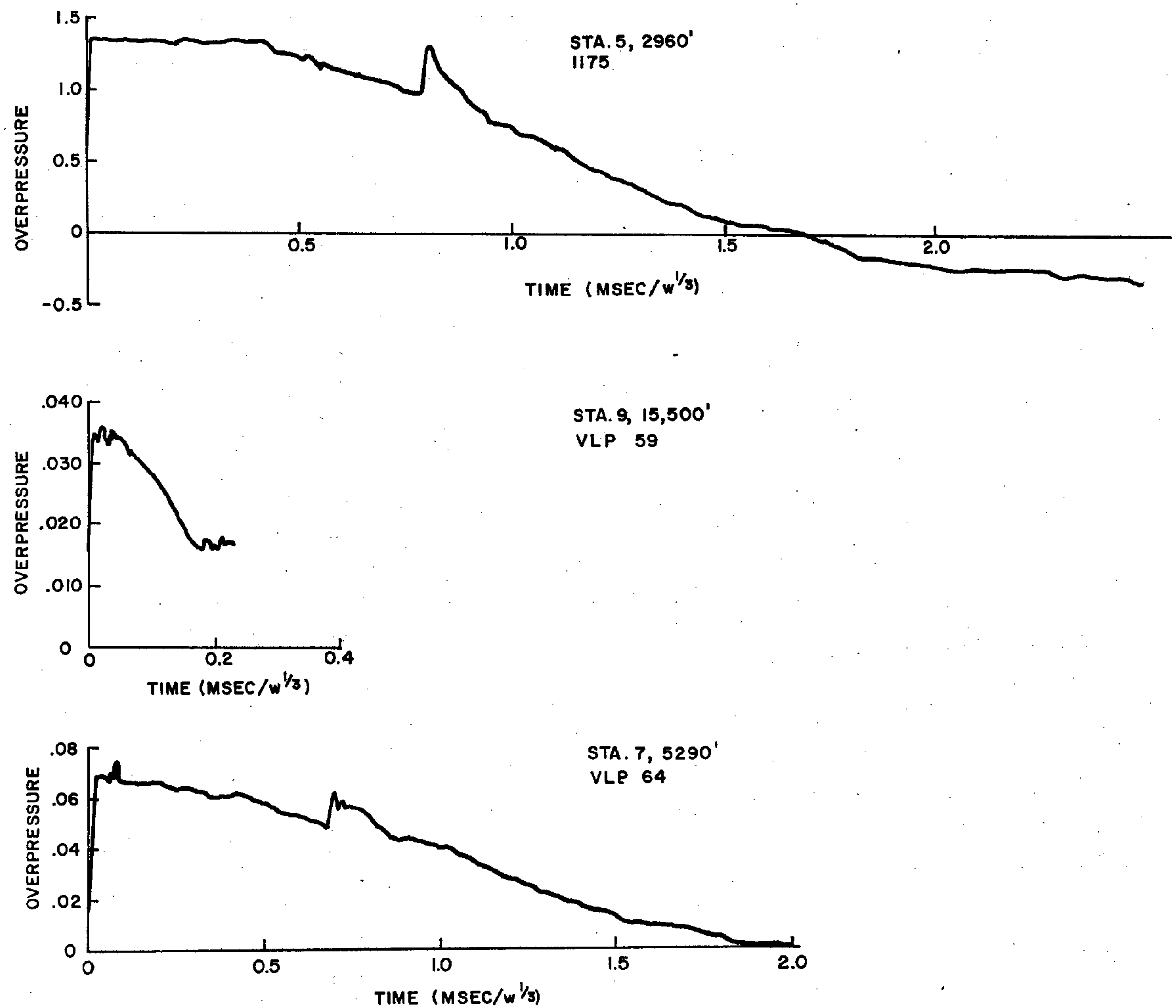

STA. 5, 2960'
1175
OVERPRESSURE
1.5
1.0
0.5
0
-0.5
0.5
1.0
1.5
2.0
TIME (MSEC/w^1/3)
STA. 9, 15,500'
VLP 59
OVERPRESSURE
.040
.030
.020
.010
0
0
0.2
0.4
TIME (MSEC/w^1/3)
STA. 7, 5290'
VLP 64
OVERPRESSURE
.08
.06
.04
.02
0
0
0.5
1.0
1.5
2.0
TIME (MSEC/w^1/3)

Figure 2.1

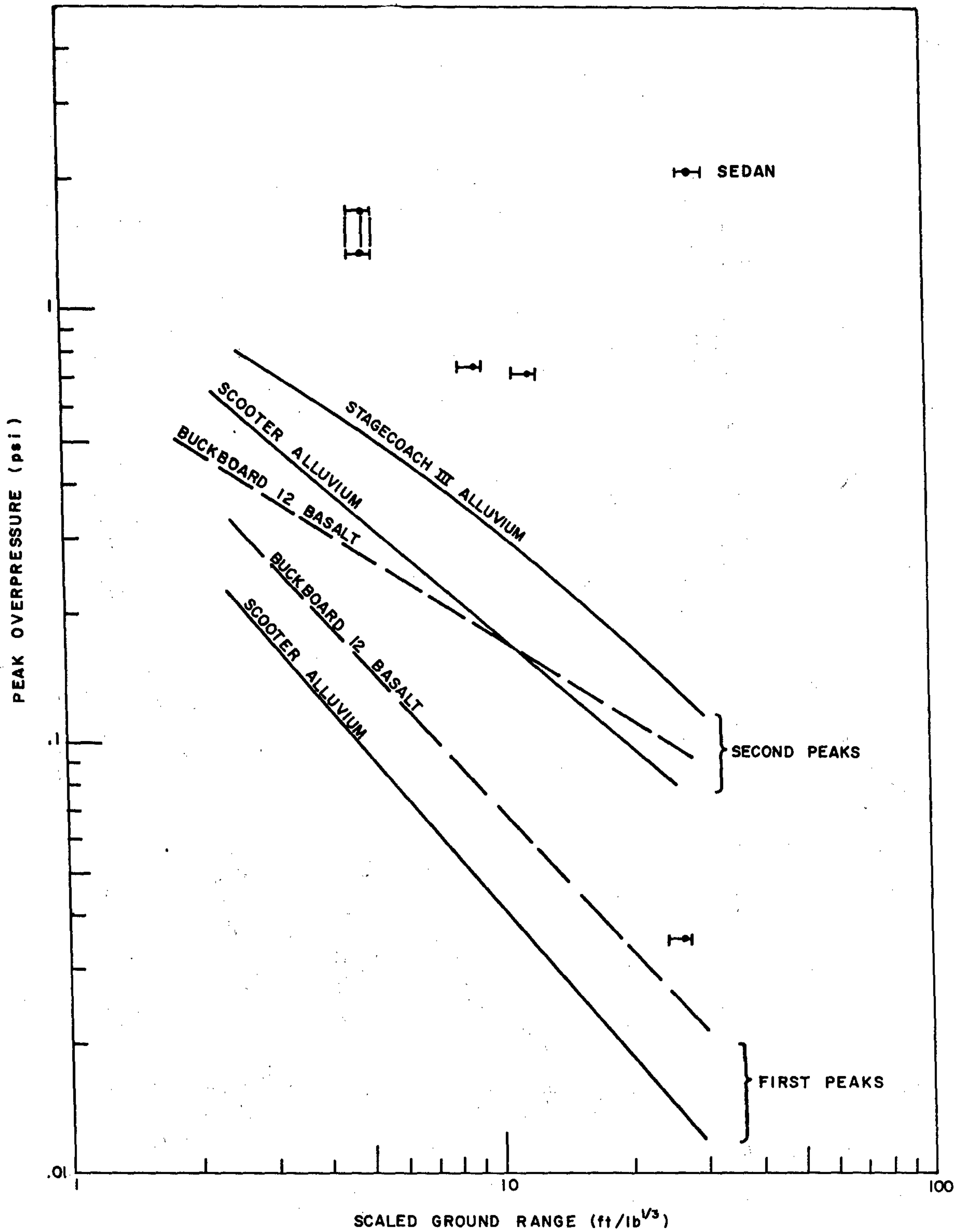

SEDAN
STAGECOACH III ALLUVIUM
SCOOTER ALLUVIUM
BUCKBOARD 12 BASALT
BUCKBOARD 12 BASALT
SCOOTER ALLUVIUM
SECOND PEAKS
FIRST PEAKS
PEAK OVERPRESSURE (psi)
1
.1
.01
1
10
100
SCALED GROUND RANGE (ft/lb^1/3)

Figure 2.2

2.3 Positive Phase

In Figure 2.3, the scaled duration of the positive phase is shown as a function of scaled ground range. It is compared with Scooter and Stagecoach III values.

Figure 2.4 shows the scaled positive-phase impulse as a function of scaled distance, again compared with Stagecoach III and Scooter values.

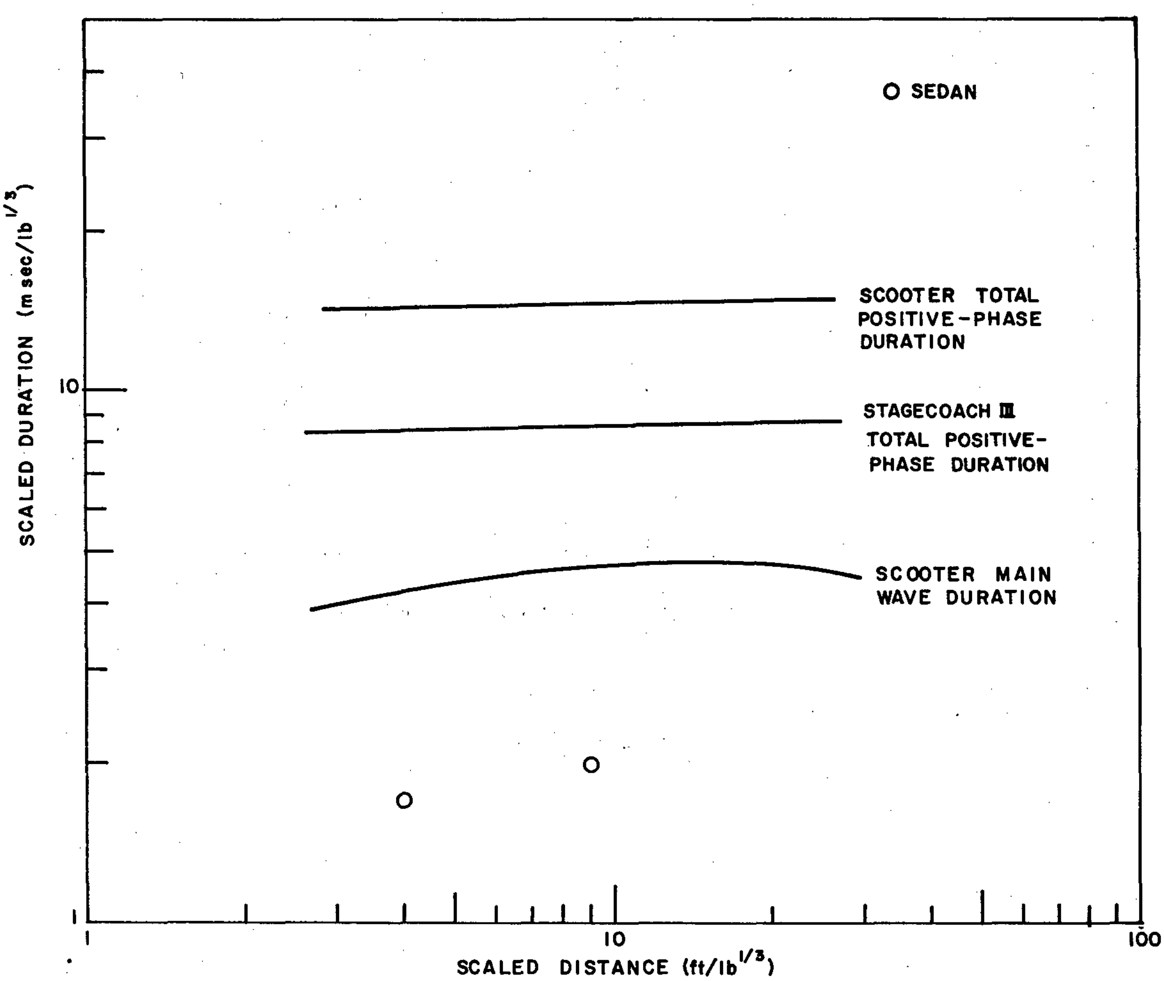
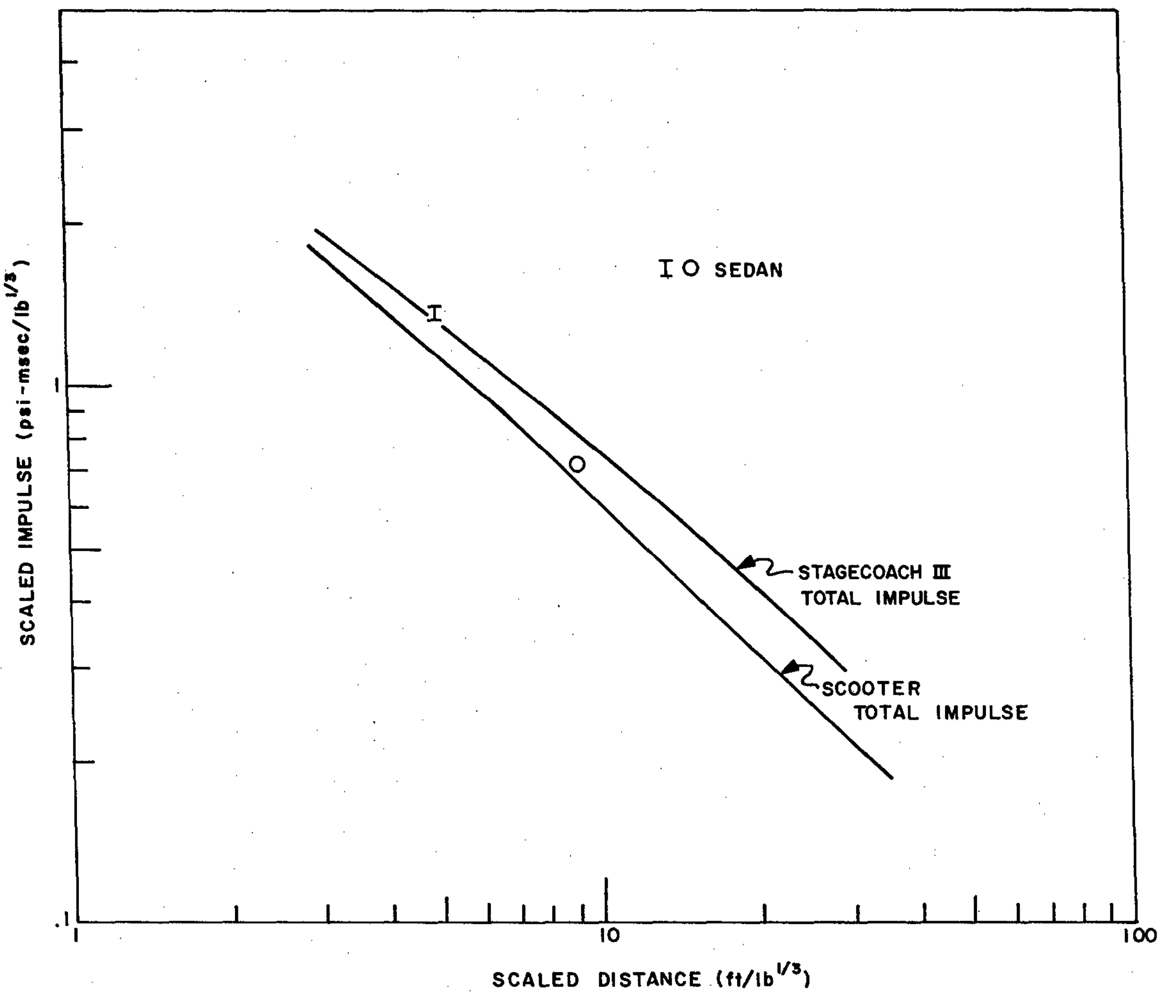


Figure 2.3



I O SEDAN
STAGECOACH III
TOTAL IMPULSE
SCOOTER
TOTAL IMPULSE
SCALED IMPULSE (psi-msec/lb$^{1/3}$)
1
.1
1
10
100
SCALED DISTANCE (ft/lb$^{1/3}$)

Figure 2.4

CHAPTER 3

DISCUSSION

3.1 Peak Overpressure

Peak overpressures were two to three times those of Stagecoach III at the same scaled distance, four or more times larger than would have been expected from Buckboard and Scooter results, and about ten times larger than would have been predicted by simple cube-root scaling of Danny Boy pressures. (This latter disparity comes from the fact that Sedan second peaks are compared with Danny Boy first peaks.) The value obtained at the most distant station is not credible and is discounted here, in spite of the fact that it agrees most nearly with the expected pressures.

3.2 Positive-Phase Impulse

The scaled values for the positive-phase impulse are about the same (Figure 2.4) as the total positive phase for Stagecoach III and Scooter. The total positive phase for Stagecoach III and Scooter includes the ground-shock-induced wave as well as the gas-venting wave. Sedan values are in effect slightly larger scalewise than those of the HE shots since ground-shock-induced impulse is included for Stagecoach III and Scooter but not for Sedan.

3.3 Positive-Phase Duration

Sedan durations were shorter (Figure 2.3) than those of the Scooter main (gas-pressure) wave by 2 to 2-1/2 times, and shorter than the Scooter total positive-phase duration by nearly a factor of 10. They were one-fifth the Stagecoach III total positive-phase duration.

3.4 Wave Shape

Except as noted below, the waveforms of the Sedan pressure waves are more like those of surface or very shallow bursts than those of comparable buried charges. There was no indication of a ground-shock-induced wave at any station, and this was unexpected. Since ground-shock-induced overpressures are proportional to surface peak velocities, and the latter are related to burial depth, the first peaks of Sedan should have been about the same as those of Stagecoach III at comparable scaled distances (that is about one-tenth the amplitude of the Sedan second-peak overpressure) and should therefore have been easily discernible on the records.

The records from 2960 feet and 5290 feet (Stations 5 and 7, respectively) show a spike occurring at later times. The spike occurs so late that it is not easily attributable to a venting of gases after the main venting.

The record from the gage at Station 5 was saturated for about the first 250 μsec, but the decay of the balance of the record permits an approximation of the peak pressure by extrapolating back to the arrival time. Ordinarily the ratio pt_+/I_+ is greater than 2, reflecting the decay of the wave in a concave upward slope. However, the values obtained at both the 2960- and 5290-foot stations show $pt_+/I_+ \approx 2$, which is in effect a triangular wave.

From consideration of Figures 2.2 to 2.4, the differences between Sedan and both the Stagecoach III and Scooter waves emerge. The differences between Sedan and Scooter are even more apparent when compared in Figure 3.1. Although the two waves have been superimposed in the figure, it should be borne in mind that absolute time is unknown for the Sedan wave. One can deduce not only that the higher gas pressures of the nuclear event caused the higher pressure peaks for Sedan, but that smaller volumes of gas and more rapid venting through a relatively larger vent caused the shorter durations of Sedan. That the scaled impulses were nearly the same suggests that the amount of gas produced was nearly equal scalewise for the HE and nuclear detonations. The shorter durations may also be due to the rapid condensation of superheated steam behind the shock front.

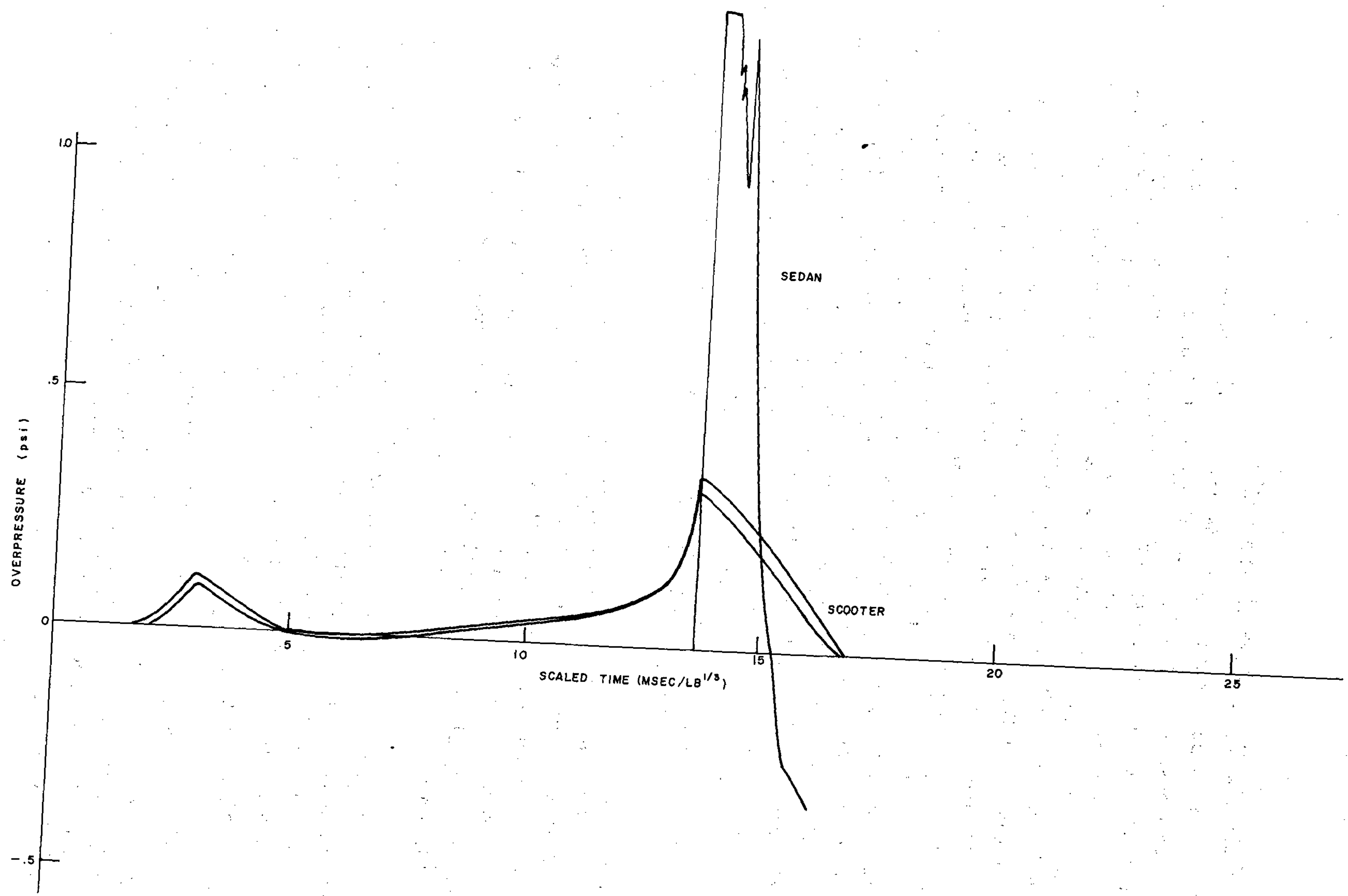

SEDAN
SCOOTER
OVERPRESSURE (psi)
1.0
.5
0
-.5
SCALED TIME (MSEC/LB$^{1/3}$)
5
10
15
20
25

Figure 3.1

3.5 Blast Suppression by Charge Burial

Blast suppression may be defined as the factor by which the peak overpressure is reduced by charge burial below some reference pressure. The reference pressure may be taken from any of several curves: the ones chosen here are (a) the Kirkwood-Brinkley[12] free-air curves for cast TNT, (b) the IBM Problem M for nuclear bursts,[13] and (c) measured values of peak overpressures from surface bursts (predominantly HE).[5] In the case of measured overpressures at the greater ranges where fractional-psi pressures are involved, meteorological effects enter into consideration and give results which should not be expected to agree with calculations for an infinite homogeneous atmosphere. Figures 3.2 to 3.4 show the blast suppression relative to (a), (b), and (c), respectively, for buried nuclear and large HE explosions. Data points for Project Sedan have been added to the figures. From these data points, it is clear that Sedan peak pressures were suppressed less than would have been expected for the Sedan burial depth. In other words, the peak overpressures are those which would have been expected from the same yield at a shallower burial depth.

The possibility exists that this observation results from improper scaling of ground range. A comparison of Sedan and Scooter peak overpressures shows that this is not the case. If ground range is proportional to W^n, n must be greater than one-half to bring the values into agreement--a scaling which is without physical justification.

Figures 3.2 to 3.4 distinguish between the suppression of the ground-shock-induced air blast and the gas-venting air blast. The former disappears for the shots at the shallower burst depths because it is overtaken by the latter at all except very close ranges. In all cases, except for the Buckboard 13 ground-shock-induced air blast, the blast suppression factor decreases with increased scaled ground range. The only nuclear shot other than Sedan for which blast suppression can be compared is Teapot ESS, which also shows a smaller blast suppression factor than the corresponding HE charge. Like Sedan, it also appears to have originated at a comparatively shallower scaled burst depth.

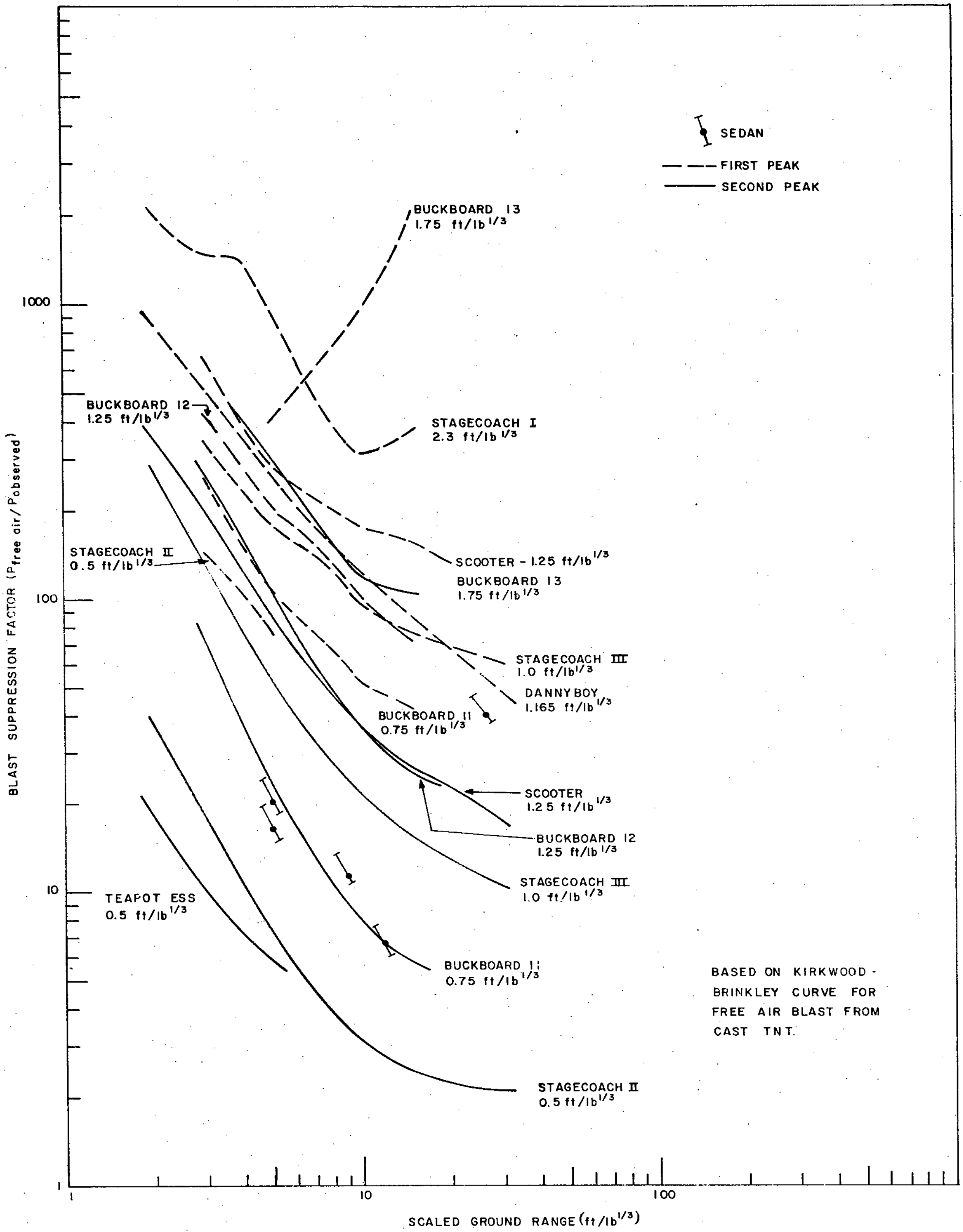

SEDAN
FIRST PEAK
SECOND PEAK
BUCKBOARD 13
1.75 ft/lb^1/3
STAGECOACH I
2.3 ft/lb^1/3
BUCKBOARD 12
1.25 ft/lb^1/3
STAGECOACH II
0.5 ft/lb^1/3
SCOOTER - 1.25 ft/lb^1/3
BUCKBOARD 13
1.75 ft/lb^1/3
STAGECOACH III
1.0 ft/lb^1/3
DANNY BOY
1.165 ft/lb^1/3
BUCKBOARD 11
0.75 ft/lb^1/3
SCOOTER
1.25 ft/lb^1/3
BUCKBOARD 12
1.25 ft/lb^1/3
STAGECOACH III
1.0 ft/lb^1/3
TEAPOT ESS
0.5 ft/lb^1/3
BUCKBOARD 11
0.75 ft/lb^1/3
STAGECOACH II
0.5 ft/lb^1/3
BASED ON KIRKWOOD - BRINKLEY CURVE FOR FREE AIR BLAST FROM CAST TNT.
BLAST SUPPRESSION FACTOR (P free air / P observed)
SCALED GROUND RANGE (ft/lb^1/3)
1000
100
10
1
1
10
100

Figure 3.2

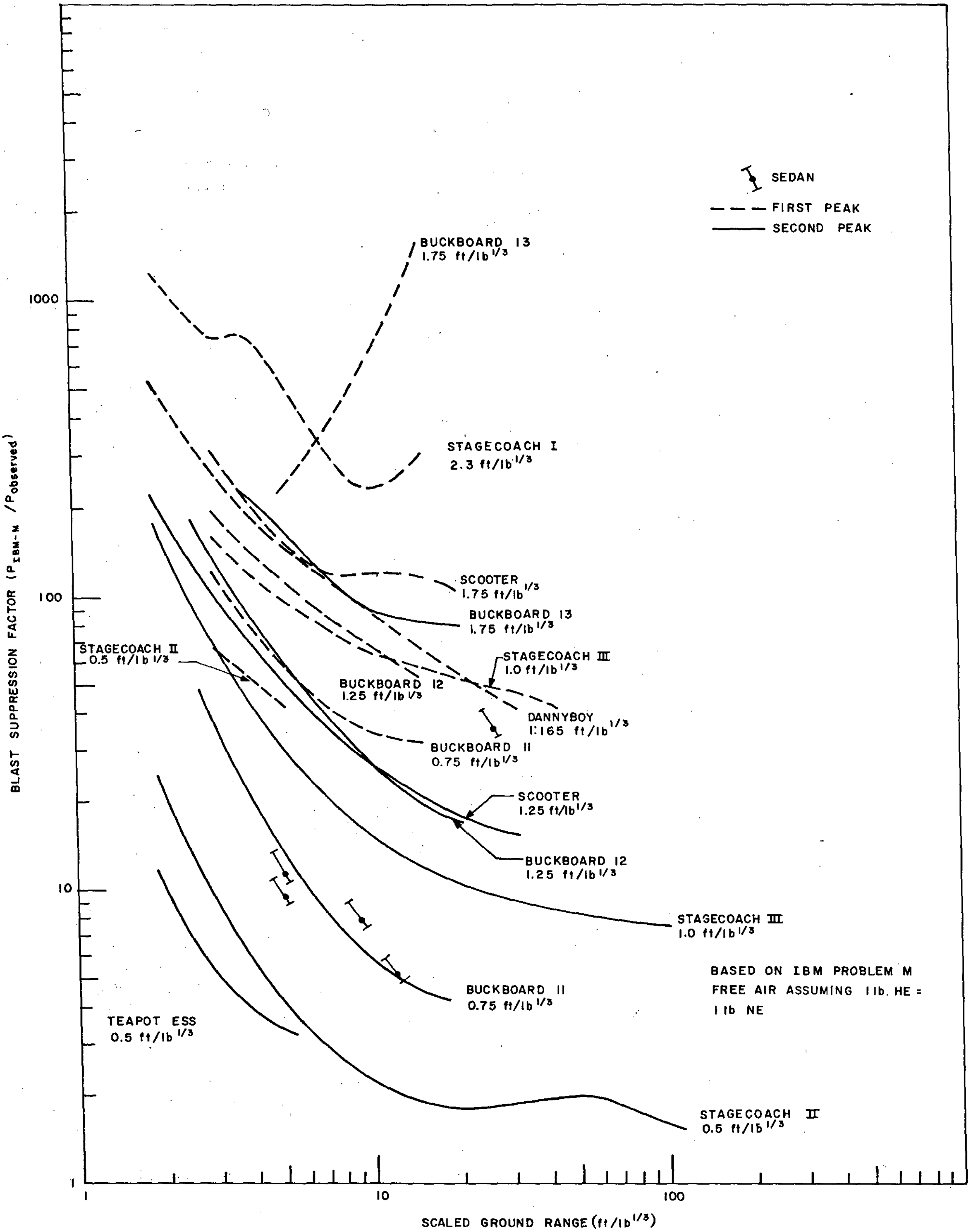
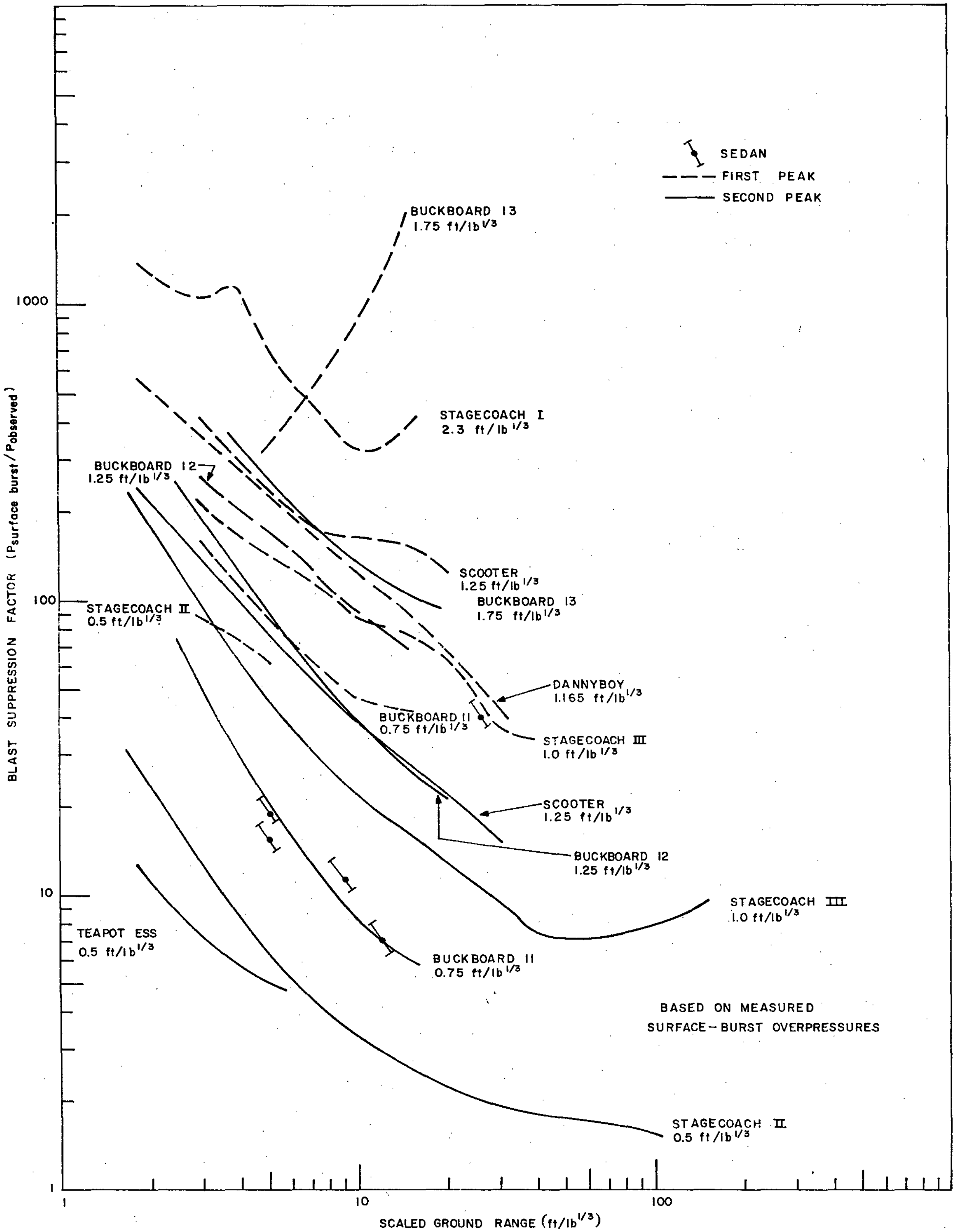

SEDAN
FIRST PEAK
SECOND PEAK
BUCKBOARD 13
1.75 ft/lb^1/3
STAGECOACH I
2.3 ft/lb^1/3
SCOOTER
1.75 ft/lb^1/3
BUCKBOARD 13
1.75 ft/lb^1/3
STAGECOACH II
0.5 ft/lb^1/3
STAGECOACH III
1.0 ft/lb^1/3
BUCKBOARD 12
1.25 ft/lb^1/3
DANNYBOY
1.165 ft/lb^1/3
BUCKBOARD II
0.75 ft/lb^1/3
SCOOTER
1.25 ft/lb^1/3
BUCKBOARD 12
1.25 ft/lb^1/3
STAGECOACH III
1.0 ft/lb^1/3
BASED ON IBM PROBLEM M
FREE AIR ASSUMING 1 lb. HE =
1 lb NE
BUCKBOARD II
0.75 ft/lb^1/3
TEAPOT ESS
0.5 ft/lb^1/3
STAGECOACH II
0.5 ft/lb^1/3
BLAST SUPPRESSION FACTOR (P_IBM-M / P_observed)
1000
100
10
1
1
10
100
SCALED GROUND RANGE (ft/lb^1/3)

Figure 3.3



SEDAN
FIRST PEAK
SECOND PEAK
BUCKBOARD 13
1.75 ft/lb$^{1/3}$
STAGECOACH I
2.3 ft/lb$^{1/3}$
BUCKBOARD 12
1.25 ft/lb$^{1/3}$
SCOOTER
1.25 ft/lb$^{1/3}$
BUCKBOARD 13
1.75 ft/lb$^{1/3}$
STAGECOACH II
0.5 ft/lb$^{1/3}$
DANNYBOY
1.165 ft/lb$^{1/3}$
BUCKBOARD 11
0.75 ft/lb$^{1/3}$
STAGECOACH III
1.0 ft/lb$^{1/3}$
SCOOTER
1.25 ft/lb$^{1/3}$
BUCKBOARD 12
1.25 ft/lb$^{1/3}$
STAGECOACH III
1.0 ft/lb$^{1/3}$
TEAPOT ESS
0.5 ft/lb$^{1/3}$
BUCKBOARD 11
0.75 ft/lb$^{1/3}$
BASED ON MEASURED
SURFACE-BURST OVERPRESSURES
STAGECOACH II
0.5 ft/lb$^{1/3}$
1000
100
10
1
1
10
100
BLAST SUPPRESSION FACTOR ($P_{surface\ burst}/P_{observed}$)
SCALED GROUND RANGE (ft/lb$^{1/3}$)

Figure 3.4

Figure 3.4 discloses that over the ground ranges between 2 and 30 ft/lb$^{1/3}$ the blast suppression factors for HE second peaks are proportional to a constant power of the burst depth (see Figure 3.5 for an example). This observation, taken at several ground ranges, permits derivation of the approximation:

$$f = \left[\frac{412}{\left(r/W^{1/3}\right)^{1.4}} + 6.4\right] dob^{2.85},$$

where f is the blast suppression factor, $r/W^{1/3}$ is the scaled ground range in ft/lb$^{1/3}$, and dob is the scaled burst depth in ft/lb$^{1/3}$.

Data are insufficient to derive a similar expression for nuclear shots, but Teapot ESS and Sedan suggest that a similar expression for nuclear detonations would have the form:

$$f = \left[\frac{a}{\left(r/W^{1/3}\right)^{\alpha}} + b\right] dob^{1.75} \quad \text{(see Figure 3.5).}$$

When peak overpressure blast suppression factors for the first (ground-shock-induced) peak were compared, there was a relationship with burst depth over a certain range of scaled ground range but not at others (Figure 3.6). Also, no consistent relationship with ground range could be derived. (Since Sedan had no first peak, it is not represented in Figure 3.6).

The blast suppression factors of Figures 3.2 to 3.4 have assumed that air blast from HE is the same as that from nuclear explosives. For comparable bursts above ground, it has been observed that the air blast from 1 kiloton of nuclear explosives (radiochemical yield) is equivalent to that from 1/2 kiloton of HE. No comparable observation has been made for below-surface bursts, nor is there adequate data to do so. Let such a relationship as is observed between blast from HE and nuclear explosives for above-surface bursts be assumed for buried explosions. Then, when comparing with IBM-M curves, the values for nuclear charges bear the same relationship to the IBM curves as they did in Figure 3.3. The HE values of blast suppression, however, shift upward (see Figure 3.7). The net effect, illustrated in Figure 3.8, is a shifting upward of blast suppression factors for HE relative to those for nuclear explosives. There is a greater spread between the suppression factors for the two types, and the rate of suppression of blast for HE is essentially twice that for the two nuclear explosions. Thus, for nuclear explosions the preceding equation may become

$$f = \left[\frac{a}{\left(r/W^{1/3}\right)^{\alpha}} + b\right] \mathrm{dob}^{1.45},$$

where the radiochemical yield is used, and suppression is the ratio of IBM-M overpressures to those observed for the nuclear explosions.

When impulse blast suppression factors (the ratio of the positive-phase impulse for a surface burst to the positive-phase impulse observed for the subsurface burst) are considered, the results are as shown in Figures 3.9 through 3.11. There is no single uniform relationship with burst depth or with ground range, as in the case of the blast suppression factors for peak overpressure (Figure 3.12). In fact, there is an abrupt change in suppression with burst depth at scaled depths deeper than Scooter and Buckboard 12, for which the total positive-phase impulse includes both the gas-venting pulse and the ground-shock-induced pulse. This suggests a difference in venting, and hence in crater mechanism, between the rising and falling portions of the crater depth-of-burst curve.

One may speculate that for shallower burst depths, the gas-venting impulse declines in importance with burial depth--declines from being the sole source for a surface burst to contributing nothing at containment. The gound-shock-induced impulse thus becomes relatively more important with burial depth, since it becomes the only source for a contained burst.

The most interesting point to be made from Figures 3.2 through 3.5 and Figures 3.9 through 3.11 is that whereas the impulse suppression values for Sedan agree with those for Scooter, Buckboard 12, and Stagecoach III HE explosions, the overpressure suppression factors are much lower, making the overpressure appear to arise from a larger yield or a shallower burst. By contrast, the scaled impulse for Danny Boy was nearly 40 times smaller than that of HE explosions at comparable scaled burst depths, while the overpressure (first peak only) was comparable to that from the other explosions.

Comparison of the Sedan blast wave with those of HE explosions at comparable burial depths suggests that the Sedan gases were confined in a relatively smaller cavity at higher pressures at the time of venting and that, as a consequence, they vented more rapidly once the mound ruptured. This is borne out by calculations. Knox[14] reports the initial conditions for Scooter and Sedan determined by the SOC (underground nuclear explosion effects) code to be:

	Scooter	Sedan
Cavity Pressure	77 bars	147.2 bars (302 bars)
Cavity Radius	42 feet	175 feet

Knox found that achieving agreement with observed surface motion required a cavity pressure of 302 bars. It is interesting that the ratio of Sedan to Scooter cavity pressures, $\frac{302}{77} \approx 4$, is about the same as the ratio of the observed peak overpressures. It may also be observed that the ratio of Sedan scaled cavity volume to that of Scooter* (0.362) is about the same as the ratio of the scaled positive-phase durations of their gas-venting pulses (0.33 to 0.5) (see Figure 3.1).

The approximate equality of scaled impulses for Scooter, Stagecoach III, and Sedan suggests that, relative to the yields, the quantity of air-blast energy available with HE is about the same as that available from a nuclear explosion in a soil with the moisture content of Sedan alluvium. This observation, together with the preceding one concerning the relatively smaller cavity and higher venting pressure of a nuclear burst, indicates either (1) a mechanistic difference between nuclear and HE explosions or (2) a change with size of charge which gives rise to a wave with a higher peak and shorter duration. In either case, higher peak pressures than those predicted by HE explosions may be expected for nuclear explosions in desert alluvium.

3.6 Inferred Yield of Sedan

From the preceding information, an apparent yield can be deduced for Sedan, albeit with considerable skepticism.

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*For the purpose here, cavity volumes may be calculated as spheres, since departures from sphericity are assumed to be similar in the two cases.

Figures 3.11 and 3.12 showed that the scaled positive-phase impulse of Sedan agrees well with those of Stagecoach III and Scooter. This would indicate that the yield was about as stated, if one assumes no difference in the impulse of nuclear and HE shots.

Figure 3.8 (based on IBM-M) shows that the peak overpressure from nuclear shots is suppressed less by burial than that from HE shots. This is true only if the yield of Sedan is 100 kilotons and its cube-root-scaled burst depth is 1.1 $ft/lb^{1/3}$. What if the rate of suppression is the same for HE and nuclear explosives, and the Sedan yield is in error? Then the Sedan value in Figure 3.8 should lie on a line through Teapot ESS and parallel to the HE data. Sedan would then have an apparent scaled burst depth of 0.75 $ft/lb^{1/3}$. Only a 300-kt device buried at 635 feet would have such a scaled burst depth. If a similar comparison is based on Figure 3.5 rather than Figure 3.8, a scaled burial depth of 0.84 $ft/lb^{1/3}$ and hence a yield of 215 kilotons is indicated.

If one returns to Figure 3.12 and again assumes that the rate of suppression is the same for HE and nuclear explosives and that the Sedan yield is in error, a line through the Teapot ESS datum indicates a scaled burst depth of 0.84 $ft/lb^{1/3}$ and hence an apparent yield of 215 kilotons. Thus, either the Sedan yield may be presumed correct, in which case the rate of suppression is not the same for HE and nuclear explosives or the suppression ratios may be assumed alike, in which case the yield must be greater than 100 kilotons. The former is, of course, the more reasonable.

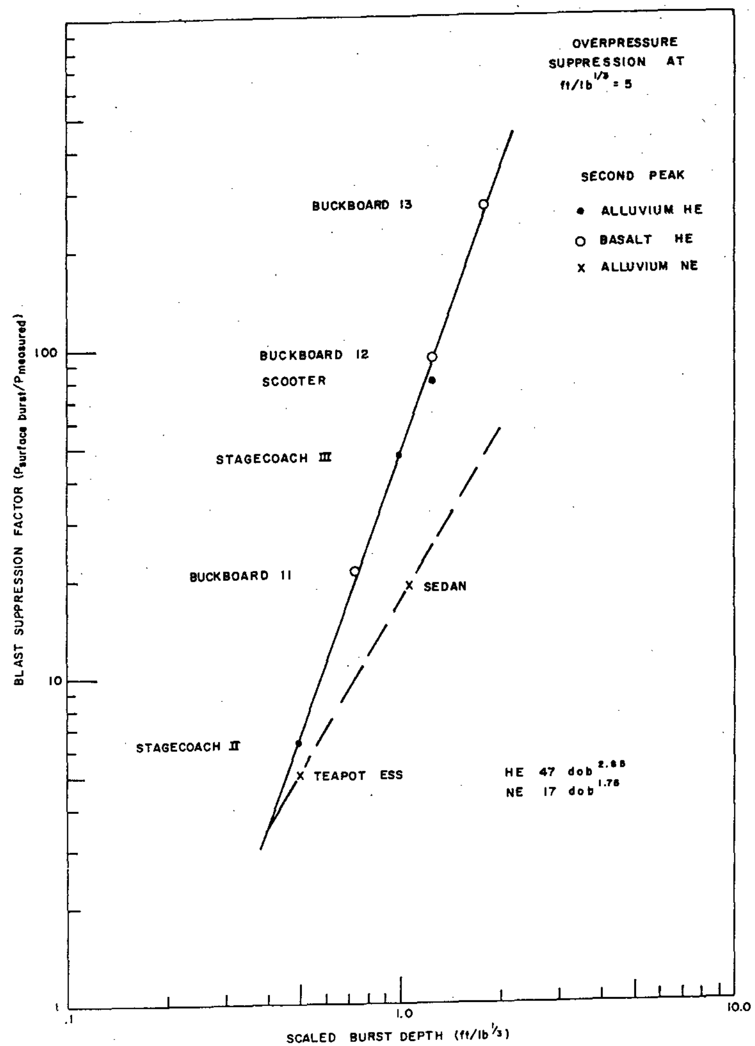

Figure 3.5

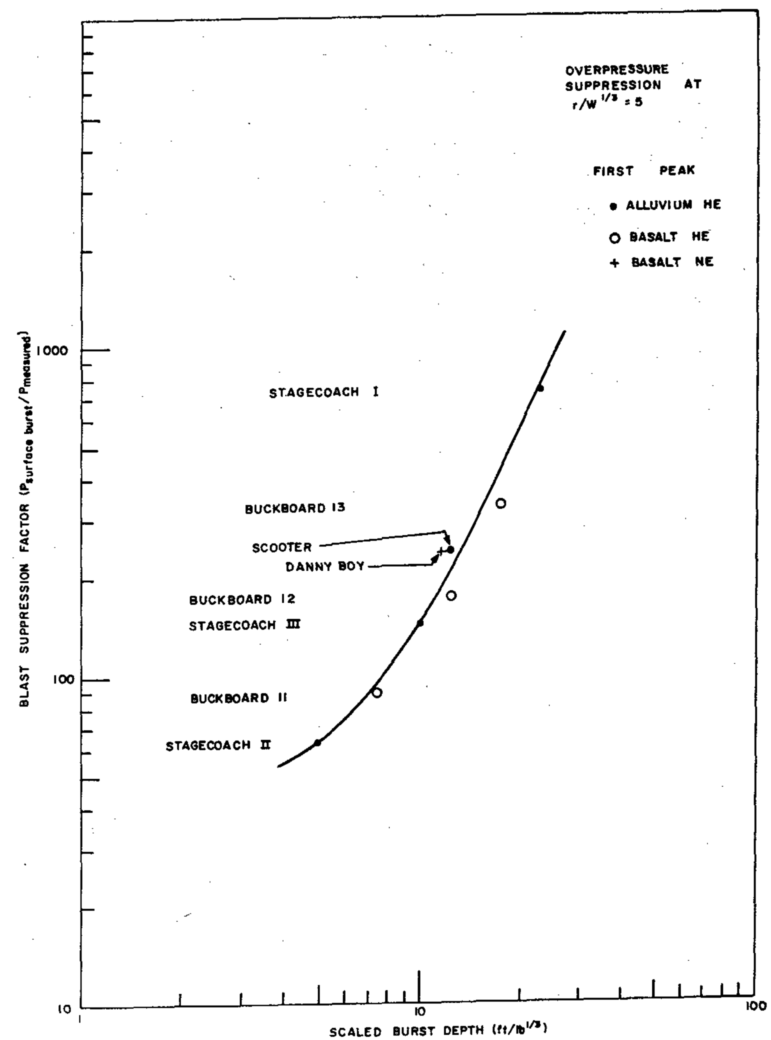

Figure 3.6

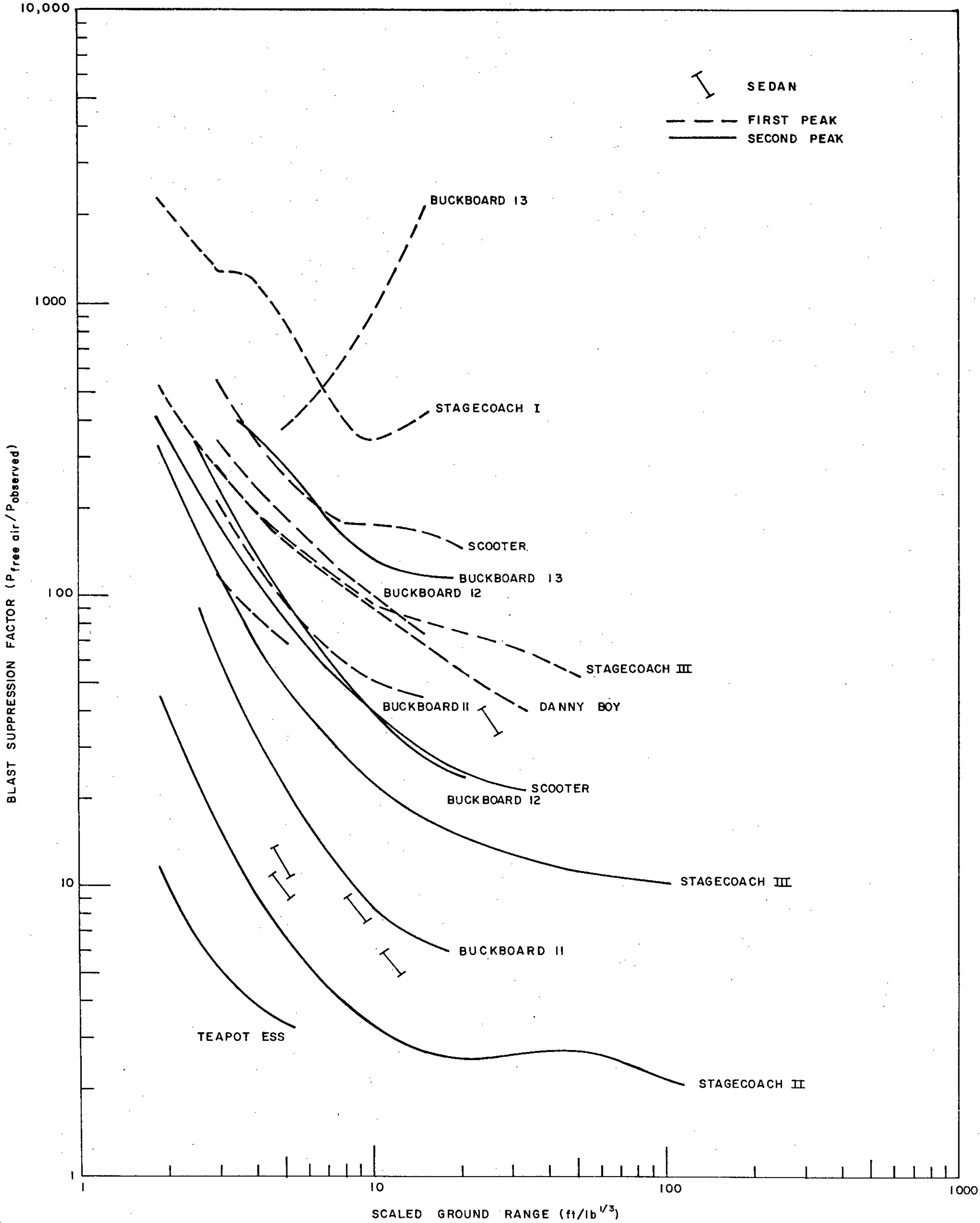
SEDAN
FIRST PEAK
SECOND PEAK
BUCKBOARD 13
STAGECOACH I
SCOOTER
BUCKBOARD 13
BUCKBOARD 12
STAGECOACH III
BUCKBOARD II
DANNY BOY
SCOOTER
BUCKBOARD 12
STAGECOACH III
BUCKBOARD II
TEAPOT ESS
STAGECOACH II
10,000
1000
100
10
1
1
10
100
1000
BLAST SUPPRESSION FACTOR ($P_{free\ air}/P_{observed}$)
SCALED GROUND RANGE ($ft/lb^{1/3}$)

Figure 3.7

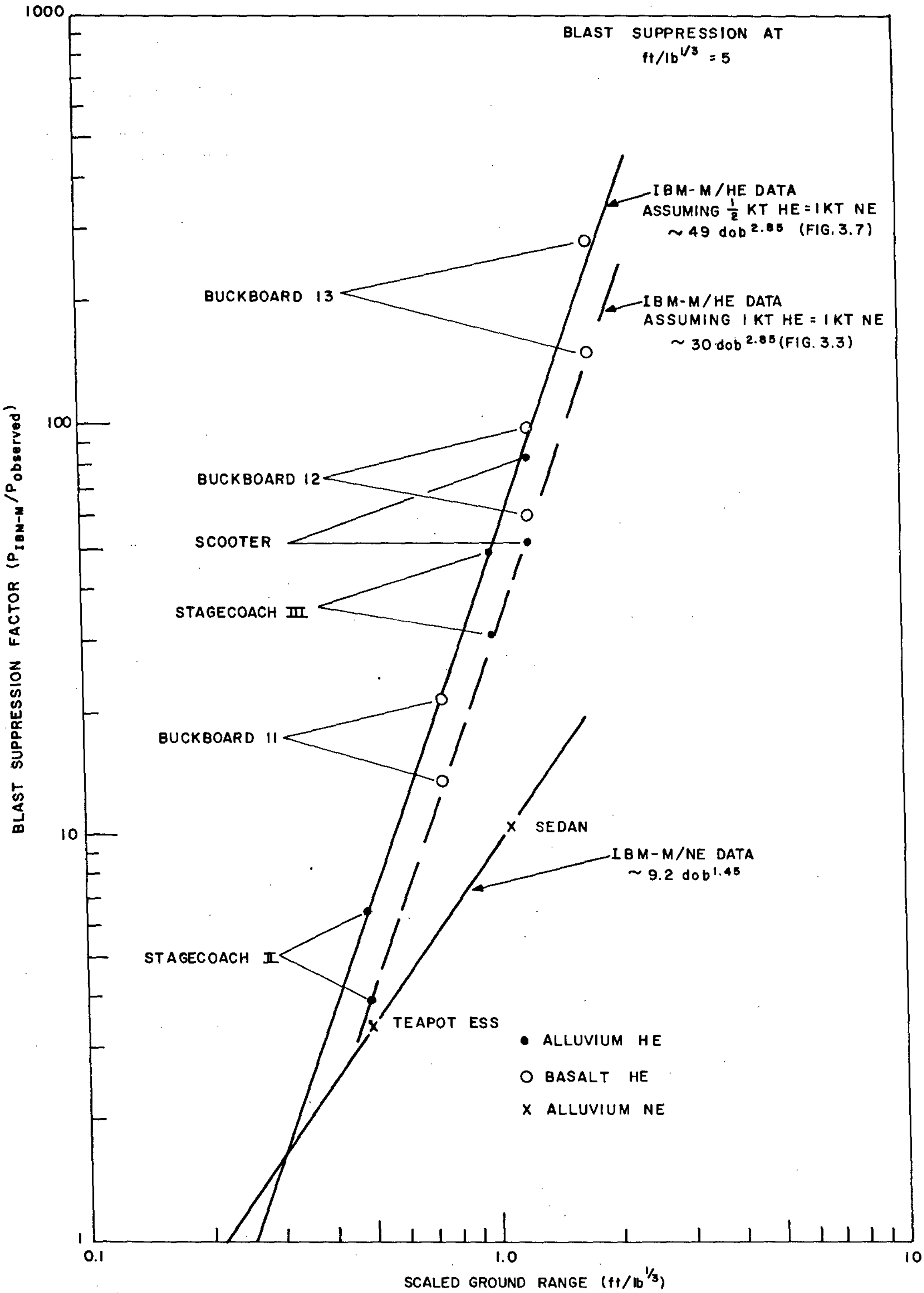
BLAST SUPPRESSION AT
ft/lb^1/3 = 5
IBM-M/HE DATA
ASSUMING 1/2 KT HE = 1KT NE
~ 49 dob^2.85 (FIG. 3.7)
IBM-M/HE DATA
ASSUMING 1 KT HE = 1KT NE
~ 30 dob^2.85 (FIG. 3.3)
BUCKBOARD 13
BUCKBOARD 12
SCOOTER
STAGECOACH III
BUCKBOARD 11
SEDAN
IBM-M/NE DATA
~ 9.2 dob^1.45
STAGECOACH II
TEAPOT ESS
ALLUVIUM HE
BASALT HE
ALLUVIUM NE
BLAST SUPPRESSION FACTOR (P_IBM-M/P_observed)
1000
100
10
1
0.1
1.0
10
SCALED GROUND RANGE (ft/lb^1/3)

Figure 3.8

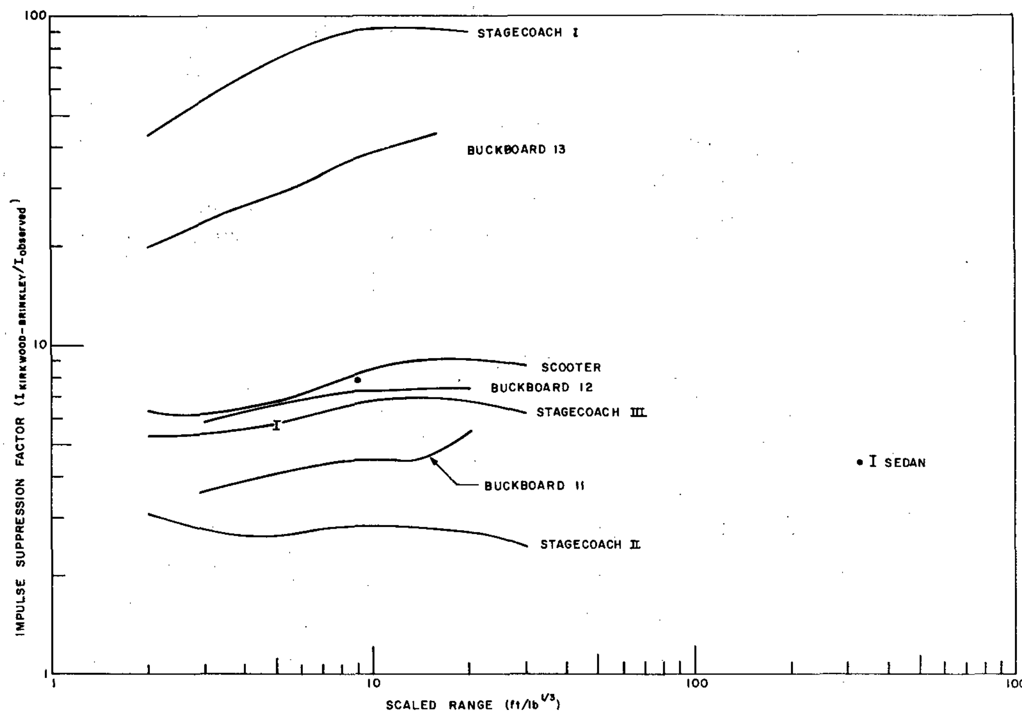

Figure 3.9

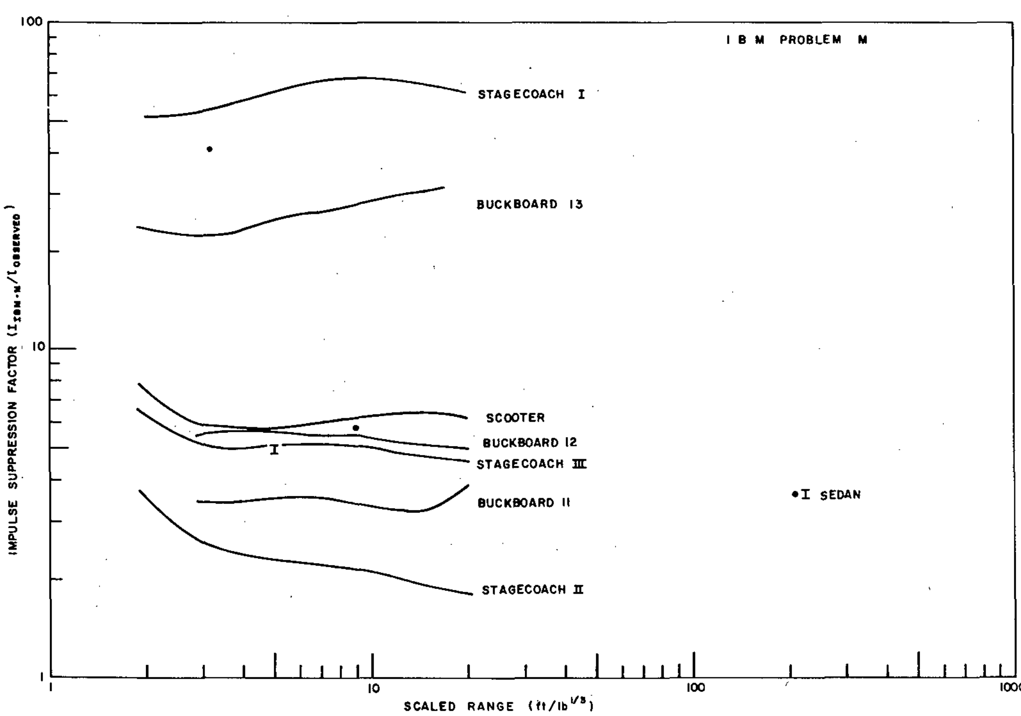

Figure 3.10

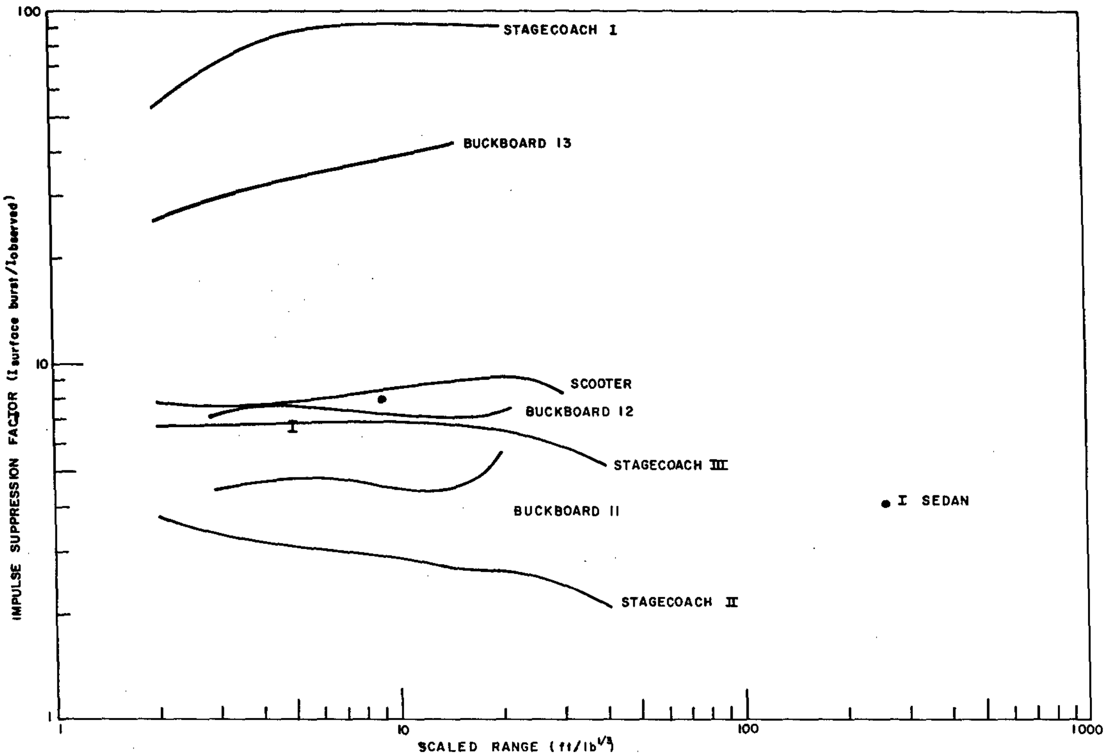

Figure 3.11

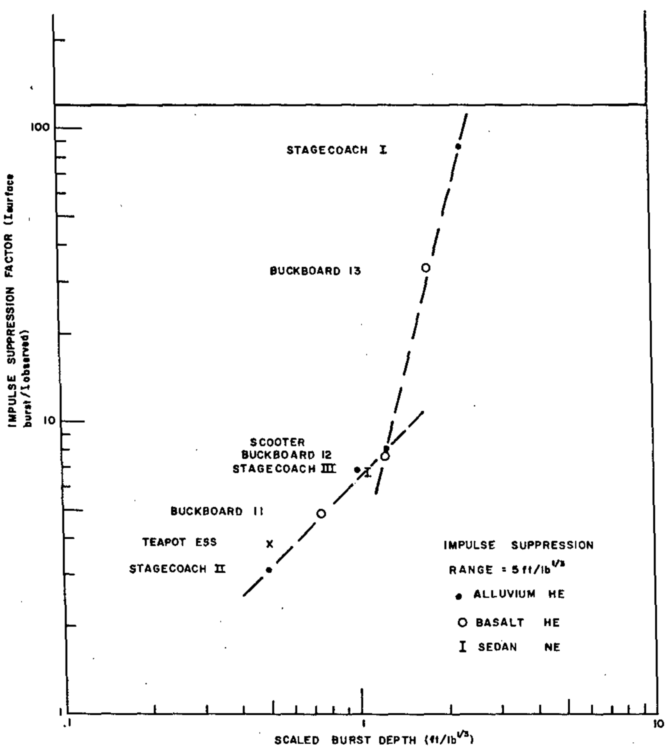

Figure 3.12

CHAPTER 4

CONCLUSIONS

Peak overpressures from Sedan did not show the ground-shock-induced pressure pulse (first peak) typical of cratering explosions. Only a gas-venting pulse (second peak) was observed.

Peak overpressures measured on Sedan were about two to three times those of Stagecoach III, four times the values which would have been predicted by the second peaks of Scooter or Buckboard 12, and ten or more times the first peaks of Scooter, Buckboard 12, and Danny Boy.

The scaled duration of the positive phase of the Sedan shock wave was less than one-half the scaled duration of the Scooter gas-venting pulse, almost one-tenth the scaled duration of the entire positive phase of the Scooter blast wave, and about one-fifth that of Stagecoach III.

The scaled impulse of the total positive phase of the Sedan blast wave is about equal to those of Stagecoach III and Scooter, indicating that the gas pressure produced by a nuclear charge in alluvium with the moisture content of the Sedan alluvium is about the same as that produced by HE.

The suppression of peak overpressure for Sedan was considerably less than would have been expected for its burial depth; similarly, the peak overpressures appear as those which would be expected from the same yield at a shallower burial depth. A blast suppression factor (ratio of peak overpressure of an equivalent surface burst to peak overpressure observed for a buried charge) for other HE explosions can be approximated by:

$$f = \left[\frac{412}{\left(r/W^{1/3}\right)^{1.4}} + 6.4 \right] dob^{2.85},$$

where $r/W^{1/3}$ is the scaled ground range in $ft/lb^{1/3}$ and dob is the scaled burial depth in $ft/lb^{1/3}$. For nuclear explosions the above expression may be expected to have the form,

$$f = \left[\frac{a}{\left(r/W^{1/3}\right)^{\alpha}} + b \right] dob^{1.75}$$

In spite of the lack of agreement of Sedan peak overpressure suppression factors with those of HE events at comparable scaled burst depths, there is quite good agreement for impulse suppression factors. There is a change in rate of impulse suppression with scaled burial depth at about the peak of the crater depth-of-burst curves which suggests a difference in crater mechanism between the rising and falling portion of the depth-of-burst curves.

Peak overpressure appears to be related to cavity pressure, at the time venting occurs, and positive-phase duration appears to be related to cavity volume at the same time.

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SC	Sandia Corporation, Sandia Base, Albuquerque, New Mexico
USC&GS	U. S. Coast and Geodetic Survey, San Francisco, California
LRL	Lawrence Radiation Laboratory, Livermore, California
LRL-N	Lawrence Radiation Laboratory, Mercury, Nevada
Boeing	The Boeing Company, Aero-Space Division, Seattle 24, Washington
USGS	Geological Survey, Denver, Colorado, Menlo Park, Calif., and Vicksburg, Mississippi
WES	USA Corps of Engineers, Waterways Experiment Station, Jackson, Mississippi
EGG	Edgerton, Germeshausen, and Grier, Inc., Las Vegas, Nevada, Santa Barbara, Calif., and Boston, Massachusetts
BYU	Brigham Young University, Provo, Utah
UCLA	UCLA School of Medicine, Dept. of Biophysics and Nuclear Medicine, Los Angeles, Calif.
NRDL	Naval Radiological Defense Laboratory, Hunters Point, Calif.
USPHS	U. S. Public Health Service, Las Vegas, Nevada
USWB	U. S. Weather Bureau, Las Vegas, Nevada
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